Age factor related to hypoxia tolerance

Capt. J. Lopez, Capt. P. Vallejo, Maj. F. Rios, R. Jimenez, Maj. J.B. del Valle, Col. J.L. Garcia-Alcon.
C.I.M.A. Arturo Soria 82. 28027 Madrid. SPAIN.
Preventive Medicine Department. H. del Aire. Madrid. SPAIN.

INTRODUCTION

Hypoxia is one of the biggest challenges that we are facing with. We define hypoxia as the absence of adequate supply oxygen to the tissues. Humans are extremely sensitive and vulnerable to the effects of oxygen deprivation and severe hypoxia can cause a deterioration of the body's functions quickly, even death (1).

According to the ethiology we distinguish four types of hypoxia: Hypoxic Hypoxia is due to a reduction of the arterial blood oxygen, Anaemic Hypoxia is due to the reduction in the oxygen-carrying capacity of the blood, Ischaemic Hypoxia is the result of the decrease of the sanguine flow in the tissues and Histotoxic Hypoxia is the result of an interference with the ability of the tissues to utilize a normal oxygen supply for oxidative processes.

We include in the first type the reduction in the oxygen tension in inspired gas, associated with exposure to altitude, so-called Hypobaric Hypoxia. This is the most common form of oxygen deficiency in aviation.

The oxygen composition of the Atmosphere is constant, 20.09 %, but as the barometric pressure decreases with the altitude, the partial pressure of oxygen also decreases. Table I shows the atmospheric pressure and the partial pressure of oxygen in different altitudes.

HIGHT		PRESSURE (mmHg)	
Feet	Meters	Atmosphere	Oxygen
0	0	760	159.6
10,000	3,048	522.6	109.7
20,000	6,096	349.1	73.3
30,000	9,144	225.6	47.3
40,000	12,192	140.7	29.5
50,000	15,240	87.3	18.3

Table I.

Modern commercial aircraft fly at cruising altitudes from about 28,000 to 43,000feet (2). Although commercial aircrafts maintain a difference of pressure between passengers' cabin and the outside, in most of them, the pressure inside the cabin during the flight is between 5,000 and 9,000 feet over sea level (3), so passengers are exposed to a light Hypobaric Hypoxia. In military aviation, however, not all the aircrafts are pressurized and the level of pressurization is very variable.

Generally, the three main causes of hypoxia in flight are:

1. Ascent to altitude of a non-pressurized aircraft without supplementary oxygen.
2. Failure of the personal breathing equipment to supply oxygen with an adequate concentration or pressure.
3. Decompression of the pressured cabin at high altitude.

When a reduced concentration of oxygen enters the lungs, it diffuses less through the alveolocapillary membrane and then appears an hypoxemia that stimulates the periphery chemoreceptors, which inform the respiratory centre, and the respiratory frequency is increased. The hyperventilation increases the arterial oxygen tension and reduces the arterial carbon dioxide tension, this leads to a respiratory alluilosis and hypocapnia.

The absence of oxygen and the hipocapnia affect intellectual and psychomotor capacity and the alertness of individual. But the physiopathologic mechanism by which the hypoxia produces this cerebral illness, remains unknown. It is believed that the absence of oxygen and the oxidative failure reduces the synthesis of neurotransmitters and the acetylcholine metabolism (4).

The alterations can be very variable, but the two main problem in aviation is the lost of judgement (the individual in unconscious of the awareness deterioration) and of the lost of consciousness without previous symptoms.

These alterations will be more acute the higher the altitude reached. Many studies have demonstrated that the majority of the effects start from the altitudes between 5,000 and 6,000feet (1), although there can exist variable individual characteristics.

This individual variability will depend on many factors, for example, the individual capacity to compensate the changes in the cardiovascular and breathing functions; the changes in the dissociation of the oxihaemoglobin, the individual differences in the tissue capacity to tolerate the effects of hypoxia, etc.

Paper presented at the RTO HFM Symposium on "Operational Issues of Aging Crewmembers", held in Toulon, France, 11-14 October 1999, and published in RTO MP-33.

One of the factors that could influence the answer of the CNS to the effects of oxygen deprivation is age. We know that with age many of our cognitive and psychomotor capacities show a progressive decline. With age we become weaker and slower, for example, the writing speed falls in the third decade (20-29 years) and the capacity to learn and to remember also decreases (5).

However, we do not have knowledge that the central effects of oxygen deprivation, in different people, according to their age have been previously studied.

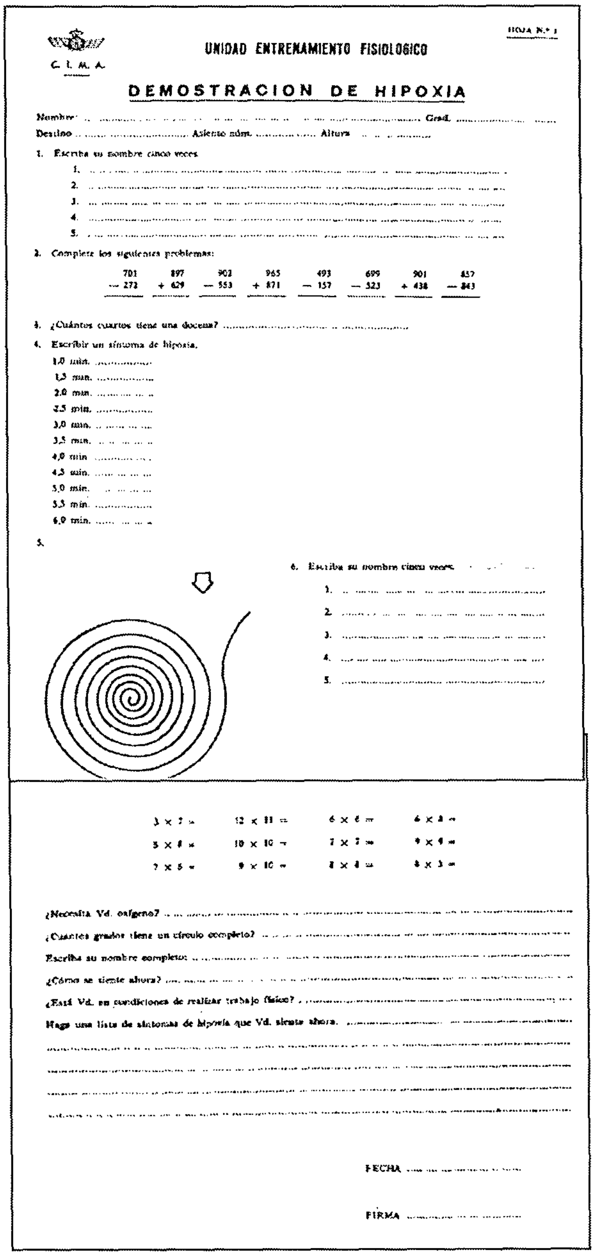
Therefore, the fundamental objective of this work is to study if, due to the age, differences exist in the performance and reaction capacity of healthy aircrew members, under hypoxia conditions. To carry it out we have quantified the degree of alterations of the cognitive functions, by means of a test completed during the flight training in a simulator of altitude or chamber of low pressure.

MATERIAL AND METHODS.

The physiological training is carry out in the Centre of Instruction of Aerospace Medicine (C.I.M.A.), and is done regularly by the fighting personnel of the Spanish Army every three or five years, depending on its specialty and destination, and in an isolated way in specialized courses. Previously each individual must overcome a medical check-up in agreement with the established medical norms for the psychophysical evaluation (6). Of these eligible personnel, we selected randomly and retrospectively (between 1993 and 1999) 161 cases. All the selected subjects had met the standards of regulation for flight in the Hypobaric Chamber, and had carried out the test of hypoxia demonstration during the training.

To carry out the training, a Hypobaric Chamber has been used. The Chamber is manufactured by Environmental Tectonic Corporation, model APTF 10M. In the course of the mock flight at 25,000 feet, after the necessary desnitrogenisation with oxygen to 100%, the subjects take off the oxygen mask and a Self-Demonstration Hypoxia Test (SDHT) begins. The *Duration,* in seconds, begins to count from the moment they take off their masks until they place it back again, either because they decide to put them on back voluntarily or because someone of the chamber crew indicates them for security reasons.

The SDHT, which appears in Figure 1, is a group of numbered tests that, the subject carries out without strict order. In the answers psychomotricity, immediate attention, short and distant memory, and the subjective symptoms that arise along the test are evaluated. From the test we obtain a *Punctuation* to each section according to their difficulty. The total sum of the *Punctuation* points could oscillate between 0 and 103 points maximum.


HOJA N.º 1

C. I. M. A.

UNIDAD ENTRENAMIENTO FISIOLOGICO

DEMOSTRACION DE HIPOXIA

Nombre: .... Grad. ....

Destino .... Asiento núm. .... Altura ....

1. Escriba su nombre cinco veces
   1. ....
   2. ....
   3. ....
   4. ....
   5. ....

2. Complete los siguientes problemas:

701	897	902	965	493	699	901	457
− 272	+ 629	− 553	+ 871	− 157	− 523	+ 438	− 843

3. ¿Cuántos cuartos tiene una docena? ....

4. Escribir un síntoma de hipoxia.
   1,0 min. ....
   1,5 min. ....
   2,0 min. ....
   2,5 min. ....
   3,0 min. ....
   3,5 min. ....
   4,0 min ....
   4,5 min. ....
   5,0 min. ....
   5,5 min. ....
   6,0 min. ....

5.

6. Escriba su nombre cinco veces.
   1. ....
   2. ....
   3. ....
   4. ....
   5. ....

3 × 7 = 12 × 11 = 6 × 6 = 6 × 8 =

5 × 8 = 10 × 10 = 7 × 7 = 9 × 9 =

7 × 5 = 9 × 10 = 8 × 8 = 8 × 3 =

¿Necesita Vd. oxígeno? ....

¿Cuántos grados tiene un círculo completo? ....

Escriba su nombre completo: ....

¿Cómo se siente ahora? ....

¿Está Vd. en condiciones de realizar trabajo físico? ....

Haga una lista de síntomas de hipoxia que Vd. siente ahora. ....

FECHA ....

FIRMA ....

Figure 1. Self-Demonstration Hypoxia Test.

To give more objectivity to the results the variable *Speed* has been created. It is the result of dividing the points obtained by the duration of the test and multiplied by 100.

The following variables have been collected by the time the tests were done,:

- *Age.* We used this variable to create *Groups of age* including all the subjects in three groups: 20-29, 30-39 and ≥40 years.
- *Weight* and *Height.* Afterwards *Body Mass Index* was calculated (*B.M.I.*). The BMI is calculated dividing the weight in kilograms and the height squared in meters. According to the NIDDM European Consent, 1993, moderate overweight is considered between 25 and 30 in men and between 24 and 30 in women, severe

overweight between 30 and 40 and obesity above 40.

- *Tobacco.* We considered that "Smoke" those that habitually consume 10 or more cigarettes a day, and "Non-smoke" the rest.
- *Time.* This variable has two categories: "1st time" includes those that have not carried out the test previously, and in "2nd or 3rd time" those who have done so.
- *Professional Activity.* We reflect the influence of their habitual work over the hypoxia tolerance. This variable has three categories: *"Non-flyers"* includes the personnel who are related with the flight but fly exceptionally, *"Flyers"* includes the air crew members of a high performance or transport aircraft, and " Parachutists " those who practice parachuting.

The results of all the variables collected are introduced and analyzed using *Statistical Package for the Social Sciences* 6.0 *(SPSS)* computer software.

A descriptive study has been carried out of the variables, using the Kolmogorov-Smirnov test for the quantitative variables in order to test the adjustment to a normal distribution. It has been calculated the mean and the standard deviation (SD) for the quantitative variables and proportions for the qualitative ones. For comparison of means we used the *"t" of Student test, "u" of Mann-Whitney test* or *ANOVA* with *Bonferroni Test* according to the characteristics of the variables and Chi^2 for the comparison of proportions. Chance probability of "p" inferior or equal to 0.05 is accepted as critical for statistical significance.

RESULTS

The total number of subjects included is 161, of those 111 (68.9%) carried out the test for the first time, and 55 (31.1%) for the second or third time. The mean age is 33.43±9.16 years (range 20-55), for the analysis we have distributed the subjects in three age groups that are described in the Table 2.

Regarding to their professional activity the subjects are classified in three groups: "non-flyers" (28,0%), "flyers" (33,5%) and "parachutist" (38,5%).

The mean of BMI is 24.36 (DS 2.23), and using 25 as cutting point for moderate obesity we found a prevalence of this condition of 35.4%. There is a tendency of less-overweight in the younger ones and there is no association between BMI and professional activity.

31% of the subjects consume tobacco, being lower the prevalence among the younger ones.

The maximum *duration* of the test was 320 seconds and the minimum 75secs. (mean 176.57 DS 47.31).

The mean *punctuation* in the tests of tolerance to hypoxia was of 20.24 (DS 11.82).

The mean *speed* of realization of the test has been 11.45(DS 6.02) with a maximum of 45.33 and a minimum of 2.86.

When stratifying the participants for the fact of having carried out the test previously we found that the subjects that carried it out for the first time, were significantly younger (P=0.02). Significant differences were also observed when stratifying by the professional activity (p <0.001). These data appear in Table 3.

To study the association of the dependent variable " *speed* " with the rest of the variables collected, the cases were divided according to the variable *time*, because of the significant differences found between first-time subjects and those of 2nd and 3rd-time.

Among the subjects that carried out the test for the first time an association between the *speed* and the *age group* was found statistically significant (P=0.007). When applying the Bonferroni test it was found that those subjects between 30 and 39 years old obtained a significantly greater mean speed than those in the group from 20 to 29. These results appear in the Figure 2. For the rest of the variables collected (BMI, consumption of tobacco and professional activity) no associations with speed was found.

In the group of subjects that had previously carried out the test, an association was not demonstrated between speed variable and age groups, neither with any other variable.

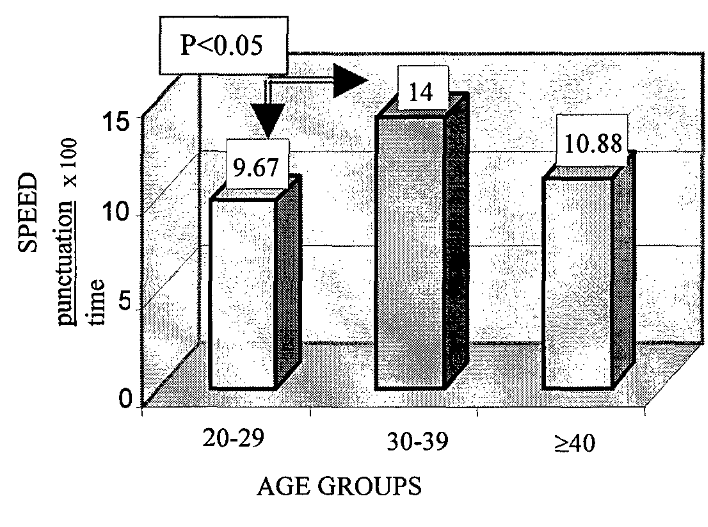


Figure 2. Mean speed by age groups.

Age Groups	N° of subjects	%	BMI	Professional activity		Speed
20-29	56	34.8%	23.64	Non-Flyers Flyers Parachutist	48.9% 14.8% 41.9%	9.77
30-39	55	34.2%	24.1	Non-Flyers Flyers Parachutist	33.3% 20.4% 46.8%	13.32
≥40	50	31.1%	25.45	Non-Flyers Flyers Parachutist	17.8% 64.8% 11.3%	11.26
Total	161	100%	24.36	Non-Flyers Flyers Parachutist	28.0% 33.5% 38.5%	11.45

Table 2. Age Groups.

		First time Mean (SD)	2ª or 3ª time Mean (SD)	Statistic Signification
AGE		32.58(9.45)	35.52(8.27)	P= 0.02
BMI		24.23(2.19)	24.65(2.33)	NS
SPEED		11.15(5.8)	12.10(6.41)	NS
PROFESSIONAL ACTIVITY	NON-FLYERS	32.1%	38.2%	P<0.001
	FLYERS	30.2%	53.1%	
	PARACHUTIST	37.7%	8.2%	
TOBACCO	NON- SMOKE	69.8%	67.3%	NS
	SMOKES	30.2%	32.7%	

Table 3. Comparison between the first and no first times that have done the test.

DISCUSSION.

The sample used for this study was picked out from the personnel of the Spanish Army related with the flight that came to the C.I.M.A. to carry out a physiological training in the hypobaric chamber.

Pilots generally begin their military career between 18-20, and must pass their physiological training in the low pressure chamber, to obtain their flight aptitude, before beginning to fly during their third course. After that, to continue maintaining the flight aptitude, they must do this physiological training periodically. For that reason the subjects that have done the test for the first time are statistically younger (p=0.02) that those that carry it out for second or third time.

The age that they stop renovating their flight aptitude is variable, although a representative age can be around 55, however, it depends on their profession. The pilots, usually, maintains his/her flight aptitude until this age, even though they've stopped flying, the parachutist and the personnel that do not fly, however, stop passing the physiologic training before.

According to the BMI in our study 35.4% are overweight. It was observed that a tendency of increase of weight existed with age.
This can be explained because to get admitted and during the first years of Military Academy they are demanded to be in good fitness.

On the other hand, no relationship exists between the BMI and the profession.

31% of the subjects consumes more than 10 cigarettes daily. It has been observed that a tendency exists to smoke more the older they get, although, it is not statistically significant. This can also be explained because the younger people maintain a better in shape.

To study the results of the SDHT, we measure the duration of the test, from the time the oxygen mask is removed until they put it on again, being very variable, between 75 and 320 seconds.

The Time of Useful Consciousness (TUC), defined as the interval of time between the interruption or decrease of the oxygen contribution and the moment that the subject is unable to carry out a certain task, in a precise and orderly way, is also very variable.

In the Table 4 we can observe the mean TUC and the Standard Deviation, calculated in 50 healthy subjects resting, breathing air at different heights (1).

ALTITUDE (feet)	TUC (seconds)	
	Mean	Standard Deviation
25,000	270	96
26,000	220	87
27,000	201	49
28,000	181	47
30,000	145	45
32,000	106	23
34,000	84	17
36,000	71	16

Table 4. Mean TUC related to the altitude.

Nevertheless, in our study we cannot consider the TUC, because the purpose of the training is that the crew member recognizes their own symptomatology under hypoxia conditions, but they do not have to reach the limit in the test. Some subjects put on their mask again voluntarily and others wait for the instructor's indication.

For this reason, a new variable, *speed* is obtained by dividing the punctuation by the duration of the test and multiplying by 100, to get, a more objective variable when studying the effects of the oxygen deprivation.

In our work, we have studied the results of the SDHT according to age, appearing significant differences when we only include the subjects that had carried out the test for the first time and no differences when we included those that had carried it out for the second or third time.

Using only the cases that carried out the test for the first time, the subjects with age between 30-39 years showed a greater speed, statistically significant ($p<0.05$) then those with 20-29 years of age and a tendency to a better answer than those >40 years, although not statistically significant.

Our results agree with the results of Kelman et al (11) who ran a test of selective attention to a control group of 18 subject at 2,000 feet and at 8,000 feet to another study group of 18 subject, finding significant differences in the realization of the test between these groups, however, when the 36 subjects familiarized with the test, those differences disappeared. In our work we have studied the results of the SDHT according to the age, appearing significant differences only when we include the subjects that had carried out the test for the first time.

Using only the cases that carried out the test for the first time, a better answer appeared, statistically significant ($p<0.05$) to the test. Calculated with the variable speed, among the second group (30-39 years) and the first one (20-29 years) and a tendency to a better answer between the second and the third (>40 years), although not statistically significant.

There are several publications where we can find examples that acute exposition to hypoxia produces alterations at the CNS.

Already in 1950, Scow et al. (7) checked this deterioration when carrying out some psychomotor tests in 17 subjects at 18,000 feet without oxygen supplement.

Fraser et al. (8) and Nordahl et al. (9), studying the postural control of 39 and 16 subjects, respectively, at different simulated heights, concluded that the affectation of the Vestibular System is a direct indicator of the effects of the Hypobaric Hypoxia in the CNS.

A more complex study was carried out by Vaernes et al. (10). They applied a test to study the cognitive and motor functions of 7 subjects at 10,000 feet high without oxygen supplement and they measured several endocrine hormones to determine the activation of stress. The conclusion was that after six and a half hours of exposition to hypoxia, alterations appeared statistically significant, mainly in the short term memory and in the time of visual reaction. However, the endocrine variables indicated that the stress was not the cause of these mistakes.

In spite of the great number of works carried out on this topic, we have not found any that study the relationships of these alterations with age.

The works that have been done studying the age factor in low pressure flights are those that aimed to demonstrate the decrease of the oxygen saturation with altitude.

Baker et al. (12) reached the conclusion that the desaturation is an important factor in accidents of non pressurized light planes. They carried out a study on the disproportionate number of accidents of light planes in the mountains of Colorado, observing that the cause of many of these accidents was that the pilot loses his of critical opinion, when flying above 14,000 feet without using oxygen.

Cottrell et al. (13) suggest that the great variability in the effects in the CNS in hypoxia conditions, is related to the level of oxyhaemoglobin saturation. They studied 42 air crew members at 8,000feet, the oxygen saturation, measure with an oxymetre, oscillated between 93 and 80%. However, they did not find relationships between these levels and age.

Bendrick et al. (3) studied 29 patients with Obstructive Chronic Lung Disease, when being evacuated in an airplane with cockpit altitudes oscillating between 5,000 and 9,000 feet, finding that the decrease of the oxygen saturation with altitude, measured with an oxymetre, had no relationships with age.

The inconvenience of this method is that the oxymetre does not measure the levels of carbonic anhydride and therefore it does not indicate the dysfunction due to the hypocapnia and also it does not differ between the carboxyhaemoglobin and the oxyhaemoglobin.

However Dillard et al. (14) studied the decrease of the oxygen saturation with a gasometry of a radial artery in 42 subjects during an exposition to hypoxia, and in this case they also did not find any relationship between the oxygen saturation and the age.

These results do not agree with ours, in our sample the subjects between 20 and 55 years, we have found that those that are between 30 and 39 years tolerate better the hypoxia, even if, as we have pointed previously the younger ones were in better shape.

We think that this is because this age group has accumulated experience and still has not suffered the deterioration of the cognitive and psychomotor capacities related to aging.

We have not found any relationship between the speed and other variables such as BMI, tobacco or professional activity. Although it may seem logical that the subject with overweight or smokers respond worse to the hypoxia, and other authors have demonstrated it in their works (13, 15), we have not obtained any difference. This cold be explained by the small sample size.

The professional activity is not related to the hypoxia tolerance, although the pilots and the parachutists are more used to hypoxia and they should tolerate it better than the group of those that are not habitually flyers. The fact that neither the physical conditions neither professional practices it they influence in the answer to hypoxia, he/she reinforces even more the age factor.

However, our study has several limitations, first of all, the original purpose of the test is to teach the subjects to recognize their own symptoms when exposed to an hypoxia atmosphere, therefore the test is not designed to quantify alterations.

In conclusion, our data suggest that the subjects in the age group of 30 to 39 years tolerate the hypoxia better, although it will be necessary to carry out new studies with more precise methods to be able to clarify the meaning of our observations.

BIBLIOGRAFÍA

1. De Hart R.L. Fundamentals of aerospace medicine. Baltimore: Williams & Wilkins, 1996; 43-58.
2. AMA Commission on Emergency Medical Services. Medical aspects of transportation aboard commercial aircraft. JAMA. 1982; 247: 1007- 11.
3. Bendrick G.A., Nicolas D.K., Krause B.A. Inflight oxygen saturation decrements in aeromedical evacuation patients. Aviat Space Environ Med. 1995 Jan. 66 (1), 40-4.
4. Gibson G.E., Petersen C., Sansone J. Decreases in amino acid and acetylcholine metabolism during hypoxia. J. Neurochem. 1981; 37: 192-201.
5. Rosenzweig M.R. Psicologia fisiológica. Berkeley: Mc Graw Hill, 1997.
6. B.O.D. nº204. 19 de Octubre 1992; 9539-63.
7. Scow J., Krasno L., Ivy A. The inmediate and accumulative effect of psycomotor performance of exposure to hypoxia, high altitude and hyperventilation. J. Aviat. Med. 1950; 21: 79-81.
8. Fraser W.D., Eastman D.E., Paul M.A. Decrement in postural control during mild hypobaric hypoxia. Aviat Space Environ Med. 1987; 58: 768-72.
9. Nordahl S.H, Aasen T., Owe J.O. Effects Of Hypobaric Hypoxia On Postural control. Aviat Space Environ Med. 1998 Jun. 66 (6), 590-5.
10. Vaernes R.J. Owe J.O., Myking O. Central nervous reactions to a 6.5 hour altitude exposure at 3048 meters. Aviat Space Environ Med. 1984; 55: 921-6.
11. Kelman G.R., Crow T.J. Impairment of mental performance at a simulated altitude of 8000 feet. Aerospace Med. 1969; 40: 981-82.
12. Baker S.P., Lamb M.H. Hazards of mountain flying: crashes in the Colorado Rockies. Aviat. Space Environ. Med. 1989; 60: 531-6.
13. Cottrell J.J., Lebovitz B.L. Inflight Arterial Saturation: Continuous Monitoring by Pulse Oximetry. Aviat. Space Environ. Med. 1995; Feb: 126-30.
14. Dillard T.A., Moores L.K., Bilello K.L. The preflight evaluation. A comparison of the hypoxia inhalation test with hypobaric exposure. Chest. 1995 Feb. 107 (2), 352-7.
15. Comroy J.P. Smoking and the anesthetic risk. Anesth. Analg. 1969; 48: 388-400.